

ELECTRON-EMITTING DEVICE, ELECTRON SOURCE USING
THE SAME, AND IMAGE FORMING APPARATUS USING THE SAME

BACKGROUND OF THE INVENTION

5 Field of the Invention

This invention relates to an electron-emitting device, an electron source constituted thereby, and an image forming apparatus such as a display apparatus which is the application thereof, and particularly to a
10 surface conduction electron-emitting device of novel construction, an electron source using the same, and an image forming apparatus such as a display apparatus which is the application thereof.

Related Background Art

15 A surface conduction electron-emitting device utilizing the phenomenon that electron emission is caused by flowing an electric current to electrically conductive film formed on a substrate.

As examples of this surface conduction electron-emitting device, there have been reported one using SnO_2 thin film [M. I. Elinson, Radio Eng. Electron Phys., 10, 1290 (1965)], one using Au thin film [G. Dittmer, Thin Solid Films, 9, 317 (1972)], one using $\text{In}_2\text{O}_3/\text{SnO}_2$ thin film [M. Hartwell and C. G. Fonsted, IEEE Trans.
20 ED Conf., 519 (1975)], and one using carbon thin film [Hisashi Araki, et al., Vacuum, Vol. 26, No. 1, P.22 (1983)].
25

In these surface conduction electron-emitting devices, it has been usual to carry out a power supplying process called "forming" on the electrically conductive film to thereby bring about a state in which
5 electron emission occurs before electron emission is effected.

Here, "forming" is to apply a constant voltage or a voltage slowly rising at a rate of e.g. 1 V/min. or so to the opposite ends of the electrically conductive
10 film, flow an electric current to the electrically conductive film, locally destroy, deform or change the quality of the electrically conductive film and bring about an electrically high resistance state to thereby
bring about a state in which electron emission occurs.

15 By this process, a fissure is formed in a portion of the electrically conductive film, and the phenomenon of electron emission is considered to be attributable to the presence of this fissure. Although in what
portion the actual electron emission occurs has not
20 been completely elucidated, the fissure and the area around it are in some cases called "on electron-emitting region" for the sake of convenience.

The applicant has already made many propositions regarding the surface conduction electron-emitting
25 device. For example, regarding the above-described "forming", the applicant discloses in Japanese Patent No. 2,854,385, U. S. Patent No. 5,470,265 and U. S.

Patent No. 5,578,897 that it is preferable to effect the forming by applying a pulse voltage to electrically conductive film.

Here, the waveform of the pulse voltage may be by
5 any of a method of maintaining the crest value constant as shown in Fig. 5A of the accompanying drawings, and a method of gradually increasing the crest value as shown in Fig. 5B of the accompanying drawings, and can be suitably chosen with the shape and material of the
10 device and the conditions of the forming taken into account.

Also, subsequently to the forming, it has been found that in an atmosphere containing organic substances, a pulse voltage is repetitively applied to
15 the electron-emitting device, whereby both of a current flowing to the device (device current I_f) and a current resulting from electron emission (emission current I_e) are increased, and this processing is called "activation".

20 This processing forms a deposit composed chiefly of carbon on an area including the fissure formed in the electrically conductive film by the "forming", and the details thereof are disclosed in Japanese Patent Application Laid-Open No. 7-235255.

25 When the surface conduction electron-emitting device as described above is applied to an image forming apparatus or the like, low power consumption

and high luminance are more required.

Accordingly, as the performance of the electron-emitting device, it has come to be required more than even that the proportion of the emission current I_e to
5 the device current I_f , i.e., the electron emission efficiency, be made higher.

Also, it is a matter of course that it is necessary to prevent a variation in performance with time by electron emission being continued from becoming
10 greater than in the prior art when such an improvement in performance is to be achieved.

SUMMARY OF THE INVENTION

It is an object of the present invention to
15 provide an electron-emitting device excellent in electron emission characteristic, an electron source using the same, and an image forming apparatus using the same.

The present invention is an electron-emitting
20 device having a pair of electric conductors disposed on a substrate in opposed relation ship with each other, and a pair of piled films composed chiefly of carbon and connected to the pair of electric conductors and disposed with a gap interposed therebetween,
25 characterized in that the piled films contain therein one or more kinds of elements selected from the group of lithium, potassium, sodium, calcium, strontium and

barium within the range of 1 mol% to 5 mol% in terms of the percentage to carbon.

Also, the present invention is an electron-emitting device provided with a pair of device electrodes disposed on a substrate in opposed relationship with each other, electrically conductive film connected to the pair of device electrodes and having a fissure between the pair of device electrodes, and a deposit composed chiefly of carbon and formed in the fissure and on an area including the fissure and having in the fissure a gap of a width narrower than the fissure, characterized in that the deposit contains therein one or more kinds of elements selected from the group of lithium, potassium, sodium, calcium, strontium and barium within the range of 1 mol% to 5 mol% in terms of the percentage to carbon.

BRIEF DESCRIPTION OF THE DRAWINGS

Figs. 1A and 1B are typical views schematically showing the construction of an electron-emitting device according to an embodiment of the present invention;

Fig. 2 is a typical cross-sectional view of an electron-emitting device according to an embodiment of the present invention;

Figs. 3A, 3B, 3C and 3D are illustrate the steps of manufacturing the electron-emitting device according to the embodiment of the present invention;

Fig. 4 is a block diagram showing the epitome of an evaluating apparatus for the electron-emitting device according to the embodiment of the present invention;

5 (Figs. 5A and 5B show the waveforms of pulse voltages used in the forming step when the electron-emitting device according to the embodiment of the present invention is prepared;

10 Fig. 6 is a typical view of an electron source according to an embodiment of the present invention;

Fig. 7 is a typical, partly broken-away perspective view of an image forming apparatus using the electron source shown in Fig. 6;

15 Fig. 8 is a typical view showing another construction of the electron source according to the embodiment of the present invention;

Fig. 9 is a typical, partly broken-away perspective view of an image forming apparatus using the electron source shown in Fig. 8; and

20 / Fig. 10 shows the waveform of a pulse voltage used in the activating step when the electron-emitting device according to the embodiment of the present invention is prepared.

25 DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the present invention, an electron-emitting device having a pair of electric conductors disposed on

a substrate in opposed relationship with each other,
and a pair of piled films composed chiefly of carbon
and connected to the pair of electric conductors and
disposed with a gap interposed therebetween is

5 characterized in that the piled films contain therein
one or more kinds of elements selected from the group
of lithium, potassium, sodium, calcium, strontium and
barium within the range of 1 mol% to 5 mol% in terms of
the percentage to carbon.

10 Also, in the present invention, an electron-
emitting device provided with a pair of device
electrodes disposed on a substrate in opposed
relationship with each other, electrically conductive
film connected to the pair of device electrodes and
15 having a fissure between the pair of device electrodes,
and a deposit composed chiefly of carbon and formed in
the fissure and on an area including the fissure and
having in the fissure a gap of a width narrower than
the fissure is characterized in the at the deposit
20 contains therein one or more kinds of elements selected
from the group of lithium, potassium, sodium calcium,
strontium and barium within the range of 1 mol% to 5
mol% in terms of the percentage to carbon.

Also, the electron source of the present invention
25 is characterized by the provision of a plurality of
electron-emitting devices disposed on a substrate, and
wirings connected to these electron-emitting devices.

Also, the image forming apparatus of the present invention is characterized by the provision of the electron source, and an image forming member for effecting image information by electrons emitted from the electron source colliding against it.

Some preferred embodiments of the present invention will hereinafter be described in detail by way of example with reference to the drawings. However, the dimensions, materials, shapes and relative disposition of constituent parts described in these embodiments are not restricted to the ranges of the present invention unless otherwise specified.

Reference is first had to Figs. 1A and 1B to describe the basic construction of an electron-emitting device according to an embodiment of the present invention. Figs. 1A and 1B are typical views schematically showing the construction of the electron-emitting device according to the embodiment of the present invention, Fig. 1A being a typical plan view thereof, and Fig. 1B being a typical cross-sectional view (a cross-sectional view taken along the line 1B-1B of Fig. 1A) thereof.

In Figs. 1A and 1B, the reference numeral 1 designates a substrate as a base body formed of an insulative material, and a pair of device electrodes 2 and 33 disposed in opposed relationship with each other are provided on this substrate 1, and electrically

Sub
A'

conductive films 4 connected to the pair of device electrodes 2 and 3 are also provided on the substrate 1.

In the illustrated embodiment, there is shown a case where as described above, an electric conductor is constituted by the device electrodes 2, 3 and the electrically conductive films 4, but an equal function as the electron-emitting device can be displayed even if the electrically conductive films 4 are eliminated and the electric conductor is constituted by only the device electrodes 2 and 3.

Also, in Figs. 1A and 1B, the reference numeral 5 typically represents a fissure formed in the electrically conductive films 4, and this fissure 5 is provided between the pair of device electrodes 2 and 3.

In Figs. 1A and 1B, the reference numeral 10 denotes deposits (piled films) composed chiefly of carbon. The deposits 10 shown are formed only on the electrically conductive films 4, but depending on the forming method, they are also formed on the device electrodes 2 and 3. In some cases, they are also formed on the other portion of the substrate 1 than the inside of the fissure 5.

These deposits 10 chiefly composed of carbon are formed not only around the fissure 5, but also in the fissure 5, and are formed in the fissure 5 so as to have a gap narrower than the fissure 5.

As another basic construction of the electron-emitting device, there is also one of a step type as shown in Fig. 2. Fig. 2 is a typical cross-sectional view of an electron-emitting device according to an embodiment of the present invention.

In Fig. 2, the reference numeral 21 designates a step-forming member formed of an insulative material and provided on the substrate 1 to form a step. In the other points, the basic construction of this embodiment is the same as that shown in Figs. 1A and 1B, and the same portions as those in Figs. 1A and 1B are given the same reference numerals.

As the nature required of the device electrodes 2 and 3, it is necessary to have sufficient electrical conductivity, and as the material thereof, mention may be made of a metal, an alloy or an electrically conductive metal oxide, or a print conductor formed of a mixture of them and glass, or a semiconductor.

To preferably effect the formation of the fissure by forming, that is, to preferably effect the imparting of electron-emitting capability, it is preferable to form the electrically conductive films 4 by fine particles of an electrically conductive substance. As the material thereof, use can be made of an electrically conductive material such as Ni, Au, PdO, Pd or Pt.

Above all, PdO is a preferred material because it

has the merits that it can readily form electrically
conductive film comprising fine particles by being
sintered in the atmosphere after organic Pd compound
film has been formed, that it is a semiconductor and is
5 therefore lower in electric conductivity than metals
and is easy to control so as to obtain a suitable
resistance value for forming, and that it can be
reduced relatively easily and therefore, after a
fissure has been formed by forming, it can be made into
10 a metal Pd to thereby reduce the resistance thereof.

The formation of the deposits 10 composed chiefly
of carbon can be effected by the aforescribed
"activating" method.

As the control of the quantity of one or more
15 kinds of elements selected from the group of lithium,
potassium, sodium, calcium, strontium and barium
(hereinafter referred to as Li, K, Na, Ca, Sr and Ba,
respectively) contained in the deposits 10 composed
chiefly of carbon, there can be adopted a method of
20 introducing a raw material gas containing desired one
of the above-mentioned elements into an atmosphere
containing organic substances when activation is
effected, and controlling the quantity thereof, or a
method of applying a solution containing desired one of
25 the above-mentioned elements in the form of an organic
metal compound or the like, and then heat-processing it
to thereby make it contain a desired element, and

controlling the amount of application of the solution.

According to my study, it has been found that when
1 mol% or more of the above-mentioned element (in the
case of a plurality, the sum total of all elements) in
5 terms of the percentage to carbon is contained,
electron-emitting efficiency is improved.

On the other hand, it has been found that if the
content becomes too great, when electron emission is
continually effected, the speed at which the emitted
10 current decreases becomes higher than that when these
elements are not contained (that is, stability is
reduced). Regarding this point as well, I have found
that if the content of the above-mentioned elements is
5 mol% or less to carbon, stability is virtually not
15 adversely affected, and have come to make the present
invention.

The reason for this is not sufficiently grasped,
but yet it is known that at least a portion of the
deposits composed chiefly of carbon has graphite
20 structure, and it is well known that the above-
mentioned elements are contained in graphite, whereby
electric conductivity is increased. It is also well
known that an oxide of the above-mentioned elements or
the like has a very low work junction, and I presume
25 that these circumstances act advantageously on an
improvement in electron-emitting efficiency. Also, I
presume that the reason why stability is adversely

effected if the content becomes great is related to the fact that the crystalline property of the portion of graphite structure is reduced.

5 Description will now be made of a more specific embodiment constructed on the basis of the above-described embodiment of the present invention.

(Embodiment of the Electron-Emitting Device)

10 An electron-emitting device according to the present embodiment is similar in construction to that shown in Figs. 1A and 1B.

A method of manufacturing the electron-emitting device according to the present embodiment will herein after be described on the basis of Figs. 1A and 1B and Figs. 3A to 3D.

15 (Step-a)

First, a pattern of photoresist was formed on the washed quartz substrate 1 so as to have openings corresponding to the shapes of the device electrodes 2 and 3, and Ti of a thickness 5 nm and Pt of a thickness 20 30 nm were successively piled thereon.

Then, the pattern of the photoresist was dissolved by an organic solvent and removed, and electrodes comprising Pt/Ti layered film were formed by the technique of lift-off. Here, the electrode interval L 25 was 50 μm , the electrode width W was 300 μm (Fig. 3A).

By the vacuum evaporation method, Cr film was formed to a thickness of 100 μm , and then, by the

technique of photolithography, the Cr film was patterned so as to have an opening corresponding to the shape of electrically conductive film which will be described later. Thereafter a solution of an organic Pd compound (ccp 4230 produced by Okuno Seiyaku Ltd.) was applied by the use of a spinner, and was dried, whereafter heat processing at 350°C was effected in the atmosphere for 13 minutes.

By this processing, electrically conductive film of a thickness 10 nm comprising PdO fine particles was formed. The sheet resistance R_s of this film was $2 \times 10^4 \Omega/\square$.

The sheet resistance R_s is an amount represented as $R = (l/w)R_s$ when the resistance value measured with a current flowed in the lengthwise direction of film having a length l and a width w is defined as R , and is represented by $R_s = \rho/t$ with resistivity as ρ and film thickness as t if film is uniform.

(Step-c)

The Cr film was removed by Cr etchant, and by the technique of lift-off, the electrically conductive film was patterned into a desired shape (Fig. 3B).

(Step-d)

The above-described device was installed in a vacuum processing apparatus, and the pressure in a vacuum chamber was lowered to 2.7×10^{-4} Pa by an exhaustor, whereafter a pulse voltage was applied to

between the device electrodes 2 and 3 to thereby effect forming, and a fissure 5 was formed in a portion of the electrically conductive film (Fig. 3C).

5 The waveform of the pulse voltage used in the forming is that shown in Fig. 5B, and the pulse width $T_1 = 1$ msec. and the pulse interval $T_2 = 10$ msec., and the processing was carried out with the crest value gradually raised at 0.1 V stop.

10 In the midst of this processing, a rectangular wave pulse of a crest value 0.1 V was inserted between the above-described pulses, and the current value was measured to thereby find the resistance value of the device. At a point of time whereat the resistance value thus found exceeded $1M\Omega$, the application of the
15 pulse was stopped and the forming was terminated.
(Step-e)

Thus, the activating step is carried out. The exhaustion in the vacuum chamber is continued, and after the pressure in the chamber lowers to 1.3×10^{-6} Pa, benzonitrile is introduced into the chamber
20 through a show leak valve mounted on the vacuum chamber. The show leak value is adjusted so that the pressure in the chamber, i.e., the pressure of benzonitrile may become 1.3×10^{-4} Pa.

25 Then, a pulse voltage is applied to between the device electrodes 2 and 3. The waveform of the applied pulse is a rectangular wave pulse as shown in Fig. 10

wherein the polarity is reversed at each pulse, and with the pulse width $T_1 = 1$ msec., the pulse interval $T_2 = 100$ msec. And the pulse crest value = 15 V, the application of the pulse was effected for 60 minutes.

5 (The time of the pulse application is a time found by a preliminary study as the time until under this processing condition, the increase in the device current I_f is saturated.

10 By this processing, deposits 10 composed chiefly of carbon were formed on an area including conductive film. The deposits 10 composed chiefly of carbon are piled in the fissure 5 so as to form a gap 6 narrower than the fissure 5 (Fig. 3D).

(Step-f)

15 The device is taken out of the vacuum chamber, and processing for causing Li to be contained in the deposits composed chiefly of carbon is effected.

20 A water solution of ethylene diamine tetraacetic acid-Li salt (Li-EDTA) was applied to the above-described device and was dried, and thereafter was subjected to heat treatment at 200°C in vacuum. At this time, the quantity of the applied Li-EDTA water solution was adjusted to thereby control the quantity of Li.

25 There were prepared samples in which the quantity of Li to carbon was 1 mol% (Embodiment 1), 3 mol% (Embodiment 2), 5 mol% (Embodiment 3) and 7 mol%

(comparative example 2). Further, for the purpose of comparison, there was also prepared a sample in which the addition of Li was not effected (comparative example 1).

5 The relation between the applied amount and the Li content was found by a preliminary study. At this time, the measurement of the Li content was effected by the photoelectron spectral method. The apparatus used is ESCA LAB 220I-XL produced by VG scientific Inc. In
10 the measurement, the percentage of Li/C was found from the 1s peak of Li and the 1s peak of C (carbon) observed from an area having a side of 50 μm with the fissure as the center. The measurement limits of alkali metal element and alkali earth metal element are
15 both of the order of 0.1 mol%.

 In this preliminary study, any other alkali metal and alkali earth metal elements than Li were not detected. In the sample wherein the addition of Li was not done, neither including Li was not detected.
20 (Step-g)

 Subsequently, the above-described device was again set in the vacuum apparatus, the interior of the vacuum chamber was evacuated, and the vacuum chamber and the device were maintained at 250°C for 10 hours. This
25 processing removes the molecules of water and organic substances adsorbed to the device and the interior of the vacuum chamber, and is called "stabilizing

process".

Regarding the device, the electron-emitting characteristic and a variation therein with time were measured by the use of an apparatus schematically shown in Fig. 4.

That is, a rectangular wave pulse of a pulse width 1 msec., a pulse interval 100 msec. and a crest value 15 V was applied to the device by a pulse generator 41. The interval H between the device and an anode electrode 44 was 4 mm. A constant voltage of 1 kV was applied to the anode electrode 44 by a high voltage source 43. At this time, the device current I_f and the emission current I_e were measured by an ammeter 40 and an ammeter 42, respectively, and electron-emitting efficiency $\eta = (I_e/I_f)$ was found.

It has been found that when the driving of the device is continued, both of I_e and I_f are reduced, but when the content of Li becomes great to a certain degree, the reduction in I_e and I_f becomes fast as compared with a case where Li is not contained. The comparison between the value of the electron-emitting efficiency at the only stage of the measurement and the situation of the reduction in I_e and I_f is shown in Table 1 below.

Table 1

	Compa- rative Example 1	Embodi- ment 1	Embodi- ment 2	Embodi- ment 3	Compa- rative Example 2
Li/ C(mol%)	0	1.0	3.0	5.0	7.0
$\eta(\%)$	0.12	0.17	0.19	0.19	0.19
vari- ation with time	-	○	○	○	×

In Table 1, ○ indicates that the situation of the reduction in I_e and I_f does not differ from that of a sample which does not contain Li (Comparative Example 1), and × indicates that the reduction in I_e and I_f is faster than in Comparative Example 1.

With regard also to the elements K, Na, Ca, Sr and Ba, samples were prepared by a technique similar to Embodiments 1 to 3 and Comparative Example 2, and evaluation was done. The addition of the respective elements was done by effecting heat treatment of 200°C in vacuum after a water solution of ethylene diamine tetraacetic acid salt was applied to the respective elements and was dried.

The results are as follows.

Table 2

	Embodi- ment 4	Embodi- ment 5	Embodi- ment 6	Compara- tive Example 3
K/C(nol%)	1.0	3.0	5.0	7.0
η (%)	0.18	0.19	0.20	0.19
variation with time	○	○	○	×

Table 3

	Embodi- ment 7	Embodi- ment 8	Embodi- ment 9	Compara- tive Example 4
Na/C (nol%)	1.0	3.0	5.0	7.0
η (%)	0.18	0.19	0.19	0.19
variation with time	○	○	○	×

Table 4

	Embodi- ment 10	Embodi- ment 11	Embodi- ment 12	Compara- tive Example 5
Ca/C (nol%)	1.0	3.0	5.0	7.0
η (%)	0.19	0.21	0.22	0.18
variation with time	○	○	○	×

Table 5

	Embodi- ment 13	Embodi- ment 14	Embodi- ment 15	Compara- tive Example 6
Sr/C (mol%)	1.0	3.0	5.0	7.0
η (%)	0.18	0.20	0.21	0.19
variation with time	o	o	o	x

Table 6

	Embodi- ment 16	Embodi- ment 17	Embodi- ment 18	Compara- tive Example 7
Ba/ C(mol%)	1.0	3.0	5.0	7.0
η (%)	0.18	0.20	0.20	0.19
variation with time	o	o	o	x

As seen in the results shown in Tables 1 to 6, it has been found that with regard to any of the above-mentioned elements, 1 to 5 mol% is contained in the deposit composed chiefly of carbon, whereby the rise of the electron-emitting efficiency occurs, and as compared with cases where these elements are not contained, the variation in I_e and I_f with time does not become great and preferable results are obtained.

Further, a study similar to that in the above-described cases was made with regard to a case where equal amounts of K and Sr are contained. The result is as follows.

Table 7

	Embodi- ment 19	Embodi- ment 20	Embodi- ment 21	Compara- tive Example 8
(K+Sr)/ C(mol%)	1.0	3.0	5.0	7.0
$\eta(\%)$	0.18	0.20	0.20	0.19
variation with time	o	o	o	x

It has been found that even when of the above-mentioned elements, a plurality of kinds are contained, the sum total thereof is 1 to 5 mol% in the deposit composed chiefly of carbon, whereby the rise of the electron-emitting efficiency occurs and as compared with cases where these elements are not contained, the variation in I_e and I_f with time does not become great, and preferable results are obtained.

(Embodiments of the Electron Source and the Image Forming Apparatus)

By disposing a plurality of electron-emitting devices according to the above-described embodiments of the present invention on a substrate, and forming wirings connected to these devices, an electron source can be formed.

An example of the construction is shown in Fig. 6. In Fig. 6, the reference numeral 71 designates a substrate, the reference numeral 72 denotes m X-direction wirings D_{x1} to D_{xm} , the reference numeral 73 designates n Y-direction wirings D_{y1} to D_{yn} , the

reference numeral 74 denotes the electron-emitting devices according to the embodiments of the present invention, and the reference numeral 75 designates connecting wires connecting the above-described wirings and the device together. In the intersecting portions among the X-direction wirings and the Y-direction wirings, insulating layers, not shown, are disposed so as to electrically insulate the two.

Also, an image forming apparatus can be constituted by the above-described electron source and an image forming member for forming an image by the application of electrons emitted from the electron source.

An example of the construction is shown in Fig. 7. In Fig. 7, the reference numeral 81 denotes a rear plate, the reference numeral 82 designates a support frame, the reference numeral 83 denotes a glass substrate, and the reference numeral 86 designates a face plate, and an envelope 88 is constituted by these. The aforescribed electron source is disposed in the envelope 88, and the interior of this envelope can be maintained air-tight.

Dox1 to Doxm and Doy1 to Doyn designate external terminals connected to the X-direction wirings Dx1-Dxm and the Y-direction wirings Dya to Dyn, respectively. The reference numeral 84 denotes an image forming member formed of phosphor, and the reference numeral 85

designates a metal back comprising metal evaporation film or the like, and it reflects a light emitted from the image forming member 84 toward the inside of the envelope 88 to the outside and improves the luminance thereof and also serves as an anode electrode for accelerating the electrons emitted from the electron source.

The reference numeral 87 denotes a high voltage terminal connected to the metal back, and it is connected to a voltage source for applying a high voltage to the metal back (anode electrode) 85.

In the illustrated example, the rear plate 81 and the substrate 71 of the electron source are provided discretely from each other, but when the substrate 71 has sufficient strength, it may serve also as the rear plate.

A construction as shown in Fig. 8 can also be adopted as the construction of the electron source. That is, a plurality of wirings 112 are formed in parallelism to one another on a substrate 110, and a plurality of electron-emitting devices 111 are disposed between a pair of wirings, whereby a plurality of device rows are formed.

An example of the construction of an image forming apparatus using the electron source of such a construction is shown in Fig. 9. In the case of such a construction, a plurality of grid electrodes 120

extending in a direction orthogonal to the direction of the device rows of the electron source are disposed, and have the function of modulating electron beams emitted from the electron-emitting devices belonging to one of the device rows which is selected by a driving circuit.

Each grid electrode has electron passing holes 121 for passing electrons therethrough at positions corresponding to the electron-emitting devices.

10 Dox1-Doxm designate external terminals connected to the above-described wirings. In Fig. 9, there is shown a case where odd-numbered wirings and even-numbered wirings are taken out from the side of the opposite support frame. G1 to Gn denote grid external terminals connected to respective ones of the above-described grid electrodes.

As described above, the present invention could improve the electron-emitting efficiency within a range in which adverse effect did not appear regarding the variation with time by driving, by containing in the piled films composed chiefly of carbon one or more kinds of elements selected from the group of lithium, potassium, sodium, calcium, strontium and barium within the range of 1 mol% to 5 mol% in terms of the percentage to carbon.